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We assessed the energetic status of soldiers exposed to intense physical activities in cold and warm weather. Thirty subjects performing routine field manoeuvres participated in a two phase study: group A (n=18) in the winter phase and group B (n=12) in the summer. Energy expenditure (EE) was measured by the doubly-labeled water (DLW) technique; after a single, oral dosing of deuterium oxygen-18, daily urine sample were collected for 12 successive days. Energy intake (EI) was assessed from detailed food records filled up at "real-time", and analyzed by computerized food charts. Energy balance (EB) was calculated as the difference between EI and EE for each subject. Mean (±SE) daily EE was 4281±170 and 3937±159 kcal/day for the winter and summer groups, respectively. Mean daily EI was 2792±124 kcal/day in group A and similar in group B. A negative energy balance of 1422±163 kcal/day and 924±232 kcal/day (N.S) was calculated for group A and B, respectively. We concluded that the total energy expenditure is primarily determined by the level of activity rather than by environmental conditions. Energy intake, unaffected by climate conditions, is insufficient to offset the high energy requirements under these conditions, thus, leading to a negative energy balance in these troops.

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Energy Balance in Military Recruits Performing Intense Physical Efforts Under Extreme Climate Conditions.

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Running head: Energy expenditure during military manoeuvres in extreme climates.

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Introduction

Military operations can often be a combination of intensive physical efforts alternating with long periods of minimal activity, performed in hostile weather. Under these conditions, high energy expenditures not always compensated by adequate energy intakes, has been recorded (10,24,27).

Exposure to a continuous cold stress at rest is expected to increase the energy expenditure more than two fold relative to comfort conditions, with carbohydrates serving as the main fuel for enhanced thermogenesis (28). Furthermore, the metabolic cost of any physical activity is greater when performed in the cold than in temperate climates (21). This has been supported by Shepherd and colleagues and by Van der Merwe and Holmans (24,29), reporting a high energy cost in the range of 4000-6000 kcal/day in expeditions to the Poles. Using the doubly-labelled water technique, Jones et al. (17) obtained energy expenditure values above 4000 kcal/day during military training in extremely cold weather. Stroud and Coward (26) recently reported 6500-7500 kcal/day on an Arctic expedition.

Energy expenditure in hot environment has been less well studied. Consolazi and colleagues (3,4) reported an increased metabolic rate with acute heat exposure at rest. The energy cost of physical performance in the heat was elevated, with oxygen consumption 5% higher compared to a similar performance in temperate conditions (12,20). Others have reported a decreased VO_2 during sub-maximal exercise in a hot and dry environment compared to comfortable

climatic conditions. This was accompanied by a rise in anaerobic metabolism, as indicated by lactate concentration (2,22,31,33). Little information has been obtained on the metabolic cost of military manoeuvres in hot environments. In soldiers training for jungle warfare, energy expenditure of 4750 kcal/day was measured, considerably greater than the estimated intake of 4000 kcal/day (13).

The energy cost of military life style is complex in its nature; it combines periods of intense physical activities with periods of minimal activity which are carried-out under hostile weather conditions. The metabolic cost of living under these circumstances is difficult to evaluate. Yet, the use of doubly-labelled water which does not interfere with daily routines, provides a suitable method for studying energy expenditure in this particular group.

Military Relevance

Military manoeuvre are usually being carried-out in spite of hostile weather. Yet, the energy cost of performing under these conditions is not well studied. Intensive exercise in the cold followed by prolonged immobilization is complex in terms of thermoregulation and energy expenditure. Enhanced thermogenesis is the only physiological mechanism that will determine survival under these conditions; however, it requires an adequate food supply. Changes in metabolic rate in a hot environment is controversial; both increased and decreased energy cost has been reported in different studies. A negative energy balance, if persists for a long time

period, increases the soldier's prevalence to climate related injuries and may affect the military performance of the troops. Thus, the purpose of this field study was to assess energy expenditure and energy balance in soldiers performing military operations in cold and hot climates and to adjust food supply where needed in order to ensure a balanced energy status.

SUBJECTS AND METHODS

Subjects. Thirty male infantry soldiers, aged 19-20 years old, volunteered to participate in the study. The physical characteristics of the subjects are given in Table 1. At the time of the study, they had been on active duty for a year and had completed an advanced infantry training course. Soldiers had therefore achieved a similar level of physical performance and skills. The protocol was reviewed and approved by the Ethics Committee of the Israel Defense Forces Medical Corps. The subjects gave their written informed consent after receiving a detailed explanation of the purpose and procedures involved in the study.

Protocol. A two phase study was carried out in Northern Israel: Phase I - during rainy, cold winter months (January-February) (group A; n=18). Phase II - during hot/humid summer season (July-August) (group B; A=12). The two groups were studied in the same environment and were exposed to similar sorts of activities throughout the 3-4 month of the winter and the summer seasons. Dosage, sampling and data collection

were carried out in the unit's base.

Starting one week prior to the study and during the course of the study, the subjects did not leave the base camp, except for manoeuvres, and their sole source of drinking water was the base camp tap water. For baseline isotopic analyses, water at the base camp was sampled and daily urine samples were collected from each subject for three days before dosing.

Subjects body weight (BW) was measured (±10 gr.) prior to dosing and upon termination of the study, at the same time of the day. Subjects were weighed after voiding wearing underwear only. In a blinded fashion in group A, 14 subjects received the tracer and 4 subjects who served as controls for monitoring changes in background isotopic levels, received a dose of tap water. In group B, 10 subjects received the tracer and 2 served as control.

Activity records. A daily log of the group activities was recorded by one subject in each group. Before each manoeuvre, subjects were weighed together with their equipment load. During manoeuvres, the nature of the mission, distance traveled to, and from the target, pace of the march, grade and type of terrain, climatic conditions and any special events that occurred during the training course were recorded. Heart rate was measured during manoeuvres on different days, in 11 subjects over a 16 hour period using a Uniq CIC Rotronic Heart Watch.

Climatic conditions. Four times a day at 08:00, 14:00, 20:00 and 24:00 h, temperature and relative humidity were measured

using a Rotronic Hygroskip, and wind speed was measured using a cup anemometer.

Energy intake. The subjects were allowed to eat ad libitum. Daily food consumption was recorded by each subject over the entire study. Subjects recorded their food intakes on pre-designed record cards at the time of the meal and when eating between meal snacks, under the supervision of a trained nutritionist. At the end of each day and upon return from a field manoeuvre to base camp, records were collected and reviewed by the nutritionist.

The nutrient composition for each subject's food was estimated by a computer method based on standard tables, prepared by the Military Nutrition Division of the Israel Defense Forces. These data were used to calculate individual daily caloric intakes as well as the value of food quotient (FQ). Calculations were made separately for food items provided by the base camp kitchen and food items obtained privately by each subject. The daily caloric intakes over the 12 day period were used to calculate the average individual daily energy intakes.

DLW dosing and sampling. The subjects refrained from eating three hours before and three hours following dosing. They voided immediately prior to receiving the dose. A few hours prior to the start of the study, deuterium oxide (D_2O) (99.8%, E. Merck D-6100 Darmstadt, Germany) was weighed into 10% oxygen-18 enriched water (Iso-Yeda, Rehovot, Israel). Individual aliquot of the doubly labeled water were weighed out to provide a dosage of 0.07 g/kg D_2O and 0.174

$H_2{}^{18}O$ g/kg body weight. The doses were stored in glass containers with sealed caps. Control doses with similar volumes of the base camp tap water were identically stored.

The subjects then drank the dose, using a straw carefully inserted through the Para film seal to avoid spilling or exchange of the labeled water with atmospheric moisture. The bottle was then rinsed with 100 ml of tap water which was drunk using the same straw.

Urine samples were collected 8 hours after dosing and then daily at the same time of day for the next 12 days. When subjects were on field manoeuvres for more than 24 hours, urine samples were taken immediately prior to departure and upon return. Aliquot (20 ml) of the urine samples were then frozen for subsequent isotopic analysis.

DLW analyses. Total energy expenditure, total body water (TBW) and fat free mass (FFM) were measured using the doubly labeled water method whose principle, method of calculation, validation and sources of error have been reviewed elsewhere (5,6).Isotopic enrichments were measured using a VG Isogas AquaSira isotope-ratio mass-spectrometer (VG Isogas, Ltd., Middlewich, Cheshire, U.K.). CO_2 production rates were calculated using the method described by Coward and Cole (6), and then converted to energy expenditure. Standard calorimetric equation were applied assuming mean respiratory quotient (RQ) similar to food quotient (FQ), which was evaluated from food intake records.

Nitrogen analyses. For the winter phase only (group A), total urinary nitrogen in a 24 hour urine collection was determined

by the Kjeldahl method. Protein oxidation rate (g/day) was calculated by multiplying the total urinary nitrogen by 6.25. Due to technical limitations of storing large volumes of urine, a 24h urine collection could not be performed in the summer phase.

Calculations. The ^{18}O isotopic abundance in the control subjects receiving tap water changed by -0.3 per mil over the 12 days of the study. This relatively small change indicated that at the start of the study the subjects were already at isotopic equilibrium with the local water supply, and remained in equilibrium throughout the study.

Individual energy balance and protein balance were calculated as the difference between average individual daily intake and expenditure and protein loss. Mean values for the entire group were obtained from these data. Data are given as mean ± standard error.

RESULTS

Climatic Conditions. Climatic conditions over the periods of the study are summarized in Figure 1. Dry temperature at 08:00h ranged between 1-11°C, at 14:00h between 3-21°C, at 20:00h between 7-13°C and at 24:00h temperature ranged between 0-7°C. At nights, effective temperature due to windchill dropped to -16°C. In the summer, mean dry temperature was 24±4, 30±2 and 23±2°C at 08:00h, 14:00h and 20:00h, respectively. Discomfort index (DI) ranged between 22-26 units, with the highest values measured at 14:00h.

Activity patterns. The weight load carried by each subject varied according to each soldier's task within the unit. Total weight of the subjects (body weight plus load) during the winter phase, ranged from 96 to 122 kg with a group mean of 113±2 kg. When expressed as percent of body weight, load varied from 34% to 78% (mean±SE 61±3%). During the summer phase, total weight was 103±3kg ranging between 27-61% of BW (mean±SE 49±4%).

Energy intake. Details on energy intake are given in Table 2. The total mean energy intake (EI) of group A (winter) was 2792±108 kcal/day, of which 2106±74 kcal/day were from base supplied foods and 686±75 kcal/day were from snacks and privately provided foods. For group B (summer), EI was 2857±179 kcal/day of which 70% was base provided and the remainder, privately provided. Carbohydrates, fats and proteins accounted for approximately 53, 34, and 13% and 50, 36 and 14% of the total energy intake in groups A and B, respectively.

Energy expenditure and energy balance. Values for energy intake, expenditure and balance are given in Table 3. The individual daily energy expenditure in the winter phase ranged between 3409 to 5496 kcal/day (58 - 90 kcal/kg FFM). The mean daily expenditure for group A was 4281±170 kcal/day. In the summer phase, individual EE ranged between 2991 and 4801 kcal/day (57 - 92 kcal/kg FFM). A mean negative energy balance of 1422±163 kcal/day and 924±232 was calculated for groups A and B, respectively, with no significant differences between the groups. The ratio of total energy expenditure to the basal metabolic rate (TEE/BMR), as estimated by the Schofield equation (23), ranged from 1.93 to 3.18 and from 1.75 to 2.81, in groups A and B, respectively, indicating a greater physical activity ratio (PAR) in the winter compared to the summer phase. Physical activities of moderate to heavy intensity levels, increased heart rate to 120 - 180 beats/min. over repetitive bouts of 2-3 hour each. During periods of immobilization, heart rate ranged between 55 to 90 beats/min. The mean ratio of energy intake to basal metabolic rate (EI/BMR) was similar for the two study groups (1.63 ± 0.07). The ratio of energy intake to total energy expenditure (EI/TEE) was 0.67±0.03 in group A and 0.75±0.06 in group B, representing a greater negative balance in the former.

Caloric equivalance Individual changes in body weight during the two study periods are shown in Figure 2. The mean caloric equivalence of BW change was calculated as -375±142 kcal; the mean residual caloric balance unexplained by weight loss was calculated as 1189±201 kcal/day.

<u>Protein Balance</u> Nitrogen excretion in the 24h urine collection ranged between 5.4-29.9 g/day. Protein oxidation was calculated to contribute about 10% to the total oxygen consumption. The mean protein balance was -20 kcal/day with a large inter-individual variation. No apparent correlation between individual protein and energy balance was obtained.

DISCUSSION

We obtained a high energy expenditure among infantry troops performing multifunction military activities under cold and warm climates. The energy cost of military performance was somewhat higher in cold than in hot weather (N.S.); food intake, however, was unaffected by climate conditions and was not sufficient to balance the elevated expenditure levels.

The energy status of soldiers was followed up for 12 days, which were representative of the activities and environmental conditions of troops during the entire season. Therefore, the high energy cost of operating under these conditions should be considered for its long term effect, lasting for a period of several months.

The military scenarios encountered in our study consisted of prolonged periods of movement on foot over mountainous, difficult terrain, as well as activities characterized by complete immobility in an unsheltered area, under severe weather conditions. The characteristics of the military missions were similar whether performed in the winter or in the summer phase. During the winter, although temperatures did not often drop below 0°C, the cooling effect was markedly enhanced by strong winds (-16°C equivalent windchill temperature) and rain. Thus, a temperature difference of over 30°C existed between the winter and summer phase (Figure 1).

The high energy cost of performing actual military manoeuvres was not significantly affected by climate conditions. Yet, a trend toward a greater expenditure in the cold was measured (4281±164 vs. 3877±166 kcal/day). Few factors can be suggested to explain the slightly higher EE in the winter than in the summer group: a) the heavier load carried by troops in the winter than in the summer (42±1 vs. 35±1kg, respectively), which partly consisted of cold-protection garments. b) the effort of moving to, and from the target while being exposed to hostile weather conditions of wind storms and muddy terrain. c) ambushing in a cold climate is probably associated with periods of shivering and increased heat production to compensate for augmented heat loss to the environment; thus, resulting in greater total energy expenditure. These energy expenditure values obtained for our groups are not exceptionally high in comparison with two recent works performed on cross-country skiers (25) and in an Arctic expedition (26) in which expenditure values ranged between 6500-7500 kcal/day. Our measurement are consistent with energy expenditures reported for troops training for special operations in a mild (8) and extreme cold climate (17). In jungle warfare, in a hot wet climate (13), energy expenditure ranged between 4150-5390 kcal/day; however, the DLW technique was applied in only four of the 34 participants. Others were estimated by the difference between energy intake and change in body energy.

The elevated metabolic level can be expressed by the physical activity ratio (PAR = TEE/BMR) of 2.44±0.09 and 2.31±0.09 (groups A and B, respectively), which is considerably higher than the average value of 1.78 for sedentary male subjects, as reviewed by Goldberg et al. (15). When basal metabolic rates were estimated by the method of Schofield (23), only slight variations between subjects were obtained (1581 to 1873 kcal/day) due to the similarity in physical characteristics of troops (Table 1). Thus, any variations among individuals in total energy expenditure, appear to be affected by different activity levels rather than by the basal metabolic rate.

Soldiers had unrestricted access both to food provided during meals by the base camp kitchen, and to food obtained individually from private purchases. Considering the well known phenomenon of under-reporting of food intake (1,15,19), particular care was taken to document energy intake as accurately as possible. Subjects recorded intakes at the time of food consumption both in the dining-hall and during manoeuvres, and were interviewed by trained nutritionists immediately upon return to base camp. However, energy intake values, as reported by subjects in the present study, are far below the requirements to maintain energy balance. Our results could not point to any interaction between weather conditions and food consumption. Total intake as well as diet composition were almost identical in the winter and summer phase, which strengthens the data that have been reported by the subjects.

The phenomenon of low energy intake among soldiers in spite of their increased expenditure, has been previously noted. Field studies reported food intakes ranging between 60-75% of available calories and less than 80% of the nutritional standard (10). This imbalance was even amplified in cold weather where intake did not exceed 60% of the nutritional standard (9,10,17).

Low food intake has been attributed to several factors such as food palatability and insufficient intake of water (7,10,11,32). Inadequate food consumption in the present study has been also ascribed to a tight military schedule that does not always allow for organized meals, when troops are being unexpectedly called away for duties. In addition, although dietary documentation was carried out under a close, continuous supervision of trained dietitians, we believe that some under-reporting of energy intake is inevitable under these circumstances (1,14).

The energy intake to basal metabolic rate (EI/BMR) ratio was calculated as 1.63 ± 0.07; it falls within the range reported for 68 groups thoroughly reviewed by Black et al. (1). Data on EI/TEE ratios, have also been tabulated from studies measuring energy expenditure by the doubly labeled water method (1). Non-obese subjects with sedentary life style, ranged between 0.94 to 1.14; lower EI/TEE values have been reported for male cyclists during the Tour de France (0.73) and for female athletes during rigorous training (0.66) (30,16). Similar relations of 0.68 ± 0.03 and 0.75 ± 0.06 were calculated in our study for the winter and summer

groups, respectively, and seem characteristic for highly active populations. It has been suggested that the low EI/TEE ratios reported in athletes, resulted from under-reporting of caloric intakes, by subjects whose mind was focused on matters other than keeping dietary records (1).

Changes in body weight in both groups were less than would be expected considering the apparent energy imbalance (Fig 2). This discrepancy could be explained by physiological as well as methodological factors. Firstly, changes in body weight were based on only two point weighing, one on the first and one on the last day of the study. The final weighing was performed after soldiers had been in the base camp under sedentary conditions for about 36 hours. It may have temporarily affected fluid balance and masked a real change in body weight. This methodological "noise" should be eliminated in the future by daily or at least periodical weighing, that will reflect the trend in weight changes along the study period. Secondly, is the contribution of "missing calories" due to under-reporting of food intake, which partly explains a greater negative energy balance than could be reflected by the reduction in body weight.

We may conclude that under simulated combat conditions, energy expenditure resembles the results obtained by others during field training scenarios. The total expenditure is primarily determined by the level of physical activity, rather than by environmental conditions, as seen by the minor differences in the energy cost of performing in cold vs. warm weather. Energy intake, although probably under - reported to

a certain extent, fails to offset the high energy requirements and is unaffected by climate conditions.

Recommendations

Based on the findings of the present study, the following applications were recommended:

a) Food items were added to the military menu to provide the soldiers with a greater caloric intake at the base camp kitchen. The available calories from base supplied food were increased from 3200 to 4200 kcal/day per soldier.

b) Food items taken out of base for military manoeuvres are carried in personal packs, each containing the amount of food required according to the length of the mission. This is to ensures the availability of adequate calories for each soldier during operations.

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Table 1: Physical characteristics (Mean ± SE) of group A (winter phase) and group B (summer phase).

	Group A (n=18)	Group B (n=12)
Height (cm)	176.0±1.2	178.0±1.4
Weight (kg)	70.7±1.3	67.72±1.8
TBW (kg)	42.3±0.7	37.9±1.0
Fat (%)	18±0.7	22±1.1
FFM (kg)	57.9±1.0	51.9±1.3

Table 2: Mean (±SE) total energy intake (kcal/24h) and energy from carbohydrate, fat and protein in the winter (group A) and summer (group B) phase.

	Group A	Group B
Total		
Mean±SE	2792±108	2857±179
range	(2150-3895)	(2088-3636)
CHO		
Mean±SE	1441±45	1388±82
range	(1141-1845)	(1030-1644)
Fat		
Mean±SE	929±63	1026±80
range	(521-1443)	(736-1711)
Protein		
Mean±SE	369±16	378±31
range	(270-538)	(251-658)

Table 3: Mean (±SE) energy intake, expenditure and energy balance (kcal/24h) of the winter phase (group A) and summer phase (group B).

	group A (n=18)	group B (n=12)
Energy Intake	2792±124	2857±178
Energy expenditure	281±170	3937±159
Energy Balance	-1422±163	-924±232

Figure 1: Mean (±SE) temperature (°C) during the winter and summer phase of the study, measured at 08:00, 14:00, 20:00 and 24:00h

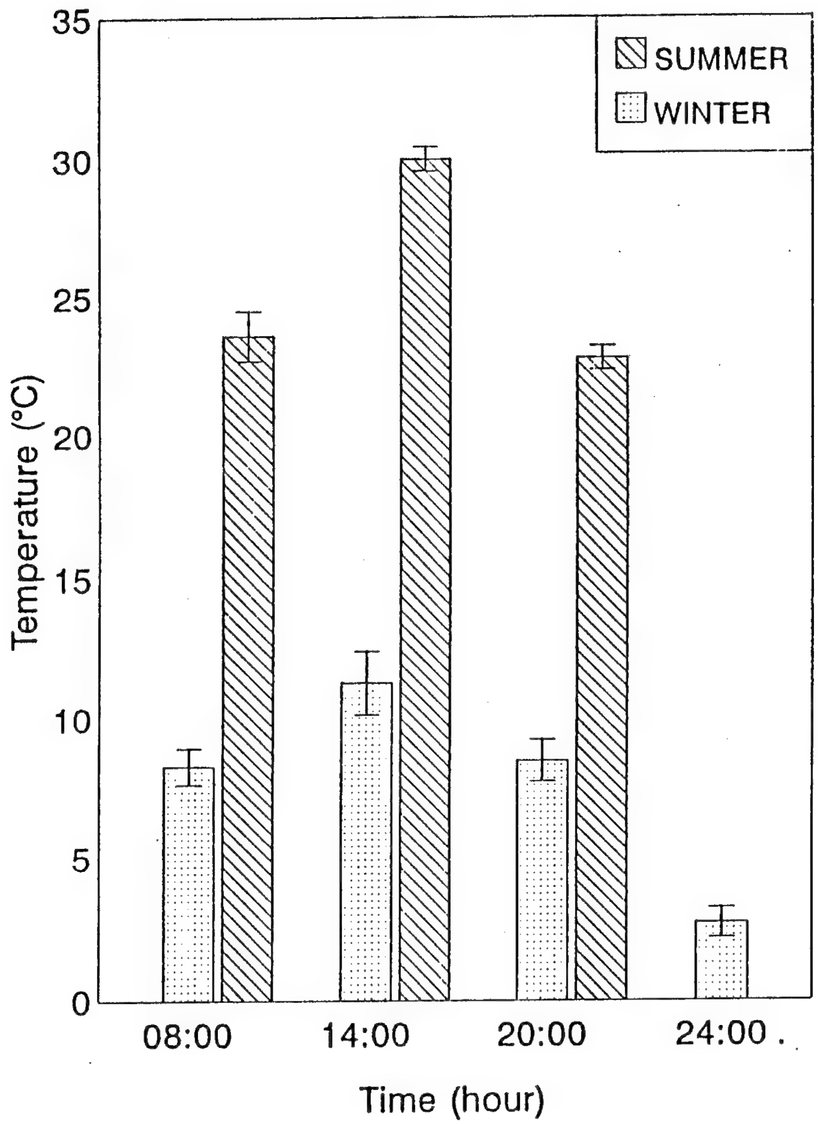
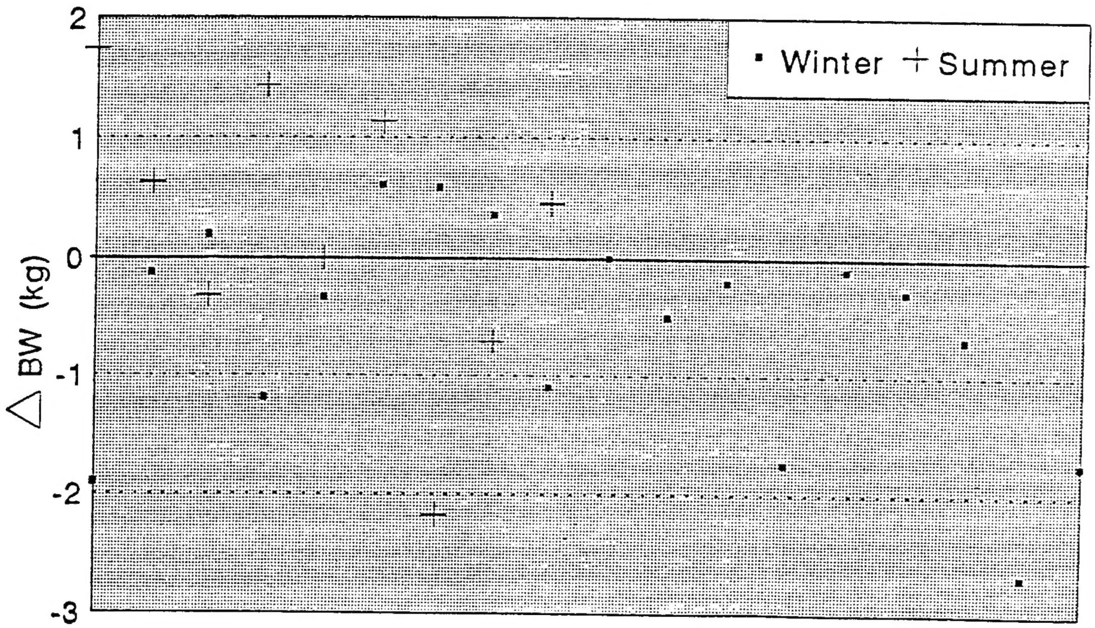


Figure 2: Individual changes in body weight (kg) during the study period.



138(tbw.r)

Apendix I:

Isotops dosing, based on soldiers' body weight*.

Group A

Subject	BW(kg)	$H_2{}^{18}O$(g)	^2H_2O(g)	Total $^2H_2{}^{18}O$(g)
1	78.70	136.94	5.51	142.45
2	76.54	112.96	4.54	117.51
3	60.32	104.96	4.22	109.18
4	59.30	103.18	4.15	107.33
5	71.64	124.65	5.01	129.67
6	66.93	116.46	4.69	121.14
7	68.19	118.65	4.77	123.42
8	70.31	122.34	4.92	127.26
9	64.09	111.52	4.49	116.00
10	69.90	121.63	4.89	126.52
11	78.04	135.79	5.46	141.25
12	66.38	115.50	4.65	120.15
13	75.68	132.21	5.32	137.54
14	76.23	132.64	5.34	137.98
15	71.05	123.63	4.97	128.60
16	72.51	126.17	5.08	131.24

* Only dosed subject appear in this table. In each group additional 2 undosed subjects served as control.

Group B

Subject	BW(kg)	$H_2{}^{18}O$(g)	^2H_2O(g)	Total $^2H_2{}^{18}O$(g)
17	63.66	110.77	4.46	115.22
18	67.68	117.76	4.74	122.50
19	64.20	111.71	4.49	116.20
20	69.32	120.62	4.85	125.47
21	57.14	99.42	4.00	103.42
22	66.17	115.14	4.63	119.77
23	73.30	127.54	5.13	132.67
24	79.44	138.23	5.56	143.79
25	69.17	120.36	4.84	125.20
26	68.72	119.57	4.81	124.38

137:tables

Apendix II:

Individual total energy intake (EI), expenditure (TEE) and balance (EB) (kcal/day) during the study period, in groups A and B.

Group A

Subject	EI	TEE	EB
1	2848	3900	-1052
2	2149	4203	-2054
3	1941	3492	-921
4	3363	3409	-46
5	2675	4216	-1541
6	2701	3984	-1283
7	2422	3798	-1376
8	2539	3545	-1006
9	2604	4153	-1549
10	2938	5122	-2184
11	2516	4692	-2176
12	3725	4596	-1771
13	2624	5370	-2296
14	3895	4554	-659

Group B

Subject	EI	EE	EB
1	3192	3879	-687
2	2120	4140	-2020
3	2582	4351	-1769
4	2448	3860	-1412
5	2264	4247	-1983
6	2946	2984	-38
7	3636	4015	-379
8	4134	4801	-667
9	3019	3504	-485
10	3192	2991	201